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EVALUATION OF STRESS ON A PILOT DURING AGRICULTURAL FLIGHTS BASED ON PHYSIOLOGICAL STUDIES

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16. Abstract

The paper presents an ergonomic analysis of the development of fatigue in a pilot during agricultural work. Selected indicators of physiological activity furing flights on PZL-101 Gawron and An-2 airplanes and Mi-2 and SM-2 helicopters are studied under various flight conditions.

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EVALUATION OF STRESS ON A PILOT DURING AGRICULTURAL FLIGHTS BASED ON PHYSIOLOGICAL STUDIES

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The pilot's work in agricultural services is characterized by /13* a high degree of difficulty. This fact is related to flights at so-called zero altitudes (from 0.5 m to several meters above ground) and to the performance of 180° turns. The highest degree of control skill and the ability to maintain constant steady attention are indispensable requirements for the performance of these tasks. Depending on climatic conditions, type of equipment and type of service, several to several tens of flights are performed daily. On the other hand, a flight may last from several to several tens of minutes. Pilots are aware of the fact that the opportunities for correcting an error are minimal in these kinds of flights and that every error may result in a crash. This places the pilot under considerable emotional strain, both before takeoff and during the actual flight. In view of the above, an analysis of the development of fatigue in a pilot is especially important as it relates to agricultural services.

Considering the diversity of aircraft used, tasks performed and the heterogeneity of climate conditions, an evaluation of the stress on a pilot is not an easy matter. This study investigated the behavior of selected indicators of physiological activity during flights on PZL-101 Gawron and An-2 airplanes and on Mi-2 and SM-2 helicopters. The studies were made under different flight conditions -- over lowland and terrain at the base of a mountain, in the spring and in the fall.

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* Numbers in the margin indicate pagination in the foreign text.

The following physiological activity indicators were studied: systolic rate, on the basis of EKG record (using telemetry or remote transmission), indicators of strength and endurance of flexor muscles in fingers and extensor muscles in back, using an electrodynamometer, the time spent in performing a task, the number of errors made during the tremorometric test and the threshold values for sensing vibrations (using an MCW-2 meter). The subjects used in these studies were pilots with extensive agricultural flight experience. The studies were conducted both under normal operating conditions and under simulation programs developed on the basis of Aviation Institute date simulating typical conditions for these flights.

The scheme used in the studies took into account measurements made during rest, before takeoff, in the pilot's cockpit, during the final approach, while performing 180° turns and during landing.

Comparison of Stress During Flight on PZL-101 and an An-2 Airplane

The systolic rate (used as a common indicator of physical and emotional stress) increased more during flights on the PZL-101 airplane than on the An-2 airplane! The differences which were about 10%, increased to 31% during landing (Fig. 1). On the other hand, in controlling the An-2 airplane, the highest values were /14 recorded during activities associated with flight over an obstruction, takeoff and performance of 180° turn.

The increase in the systolic rate recorded before takeoff, compared to the rate recorded during rest, indicates the part played by emotional stress. For pilots operating the PZL-101 airplane the rate increased up to 114% and for pilots operating the An-2 airplane, up to 131% of the value recorded during rest. (See Fig. 1 on next page.)

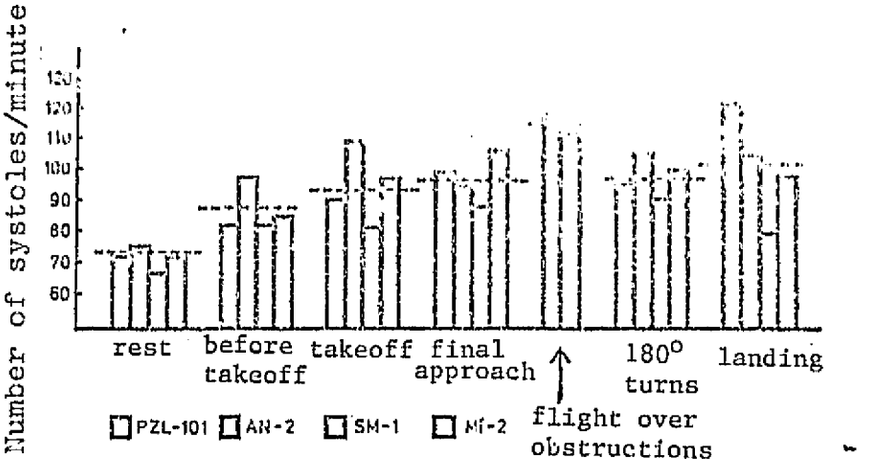

Fig. 1. Changes in systolic rate of pilots during agricultural flights on various types of airplanes and helicopters.

Data obtained from interviews, measurements of the systolic rate, studies of indicators of muscular strength and endurance indicate agreement with the substantial physical stress associated with the performance of flights.

The systolic rate (reaching occasionally 145 systoles per minute) appears to be in agreement with generally accepted criteria defining the agricultural pilot's work as strenuous physical work. However, here we must not ignore the superimposed emotional stress component The ascertained values of physiological activity indicators show that the stress is permanent, since the flights require 180° turns every 30 and sometimes even every 8 seconds. Every 180° turn requires a considerable physical effort to overcome the resistance of the rudder, and on the PZL-101 airplane, also the resistance of the trim tab.

This state of stress is confirmed by a marked drop in the endurance of muscles in upper extremities to 30% of the

TABLE 1

SYSTOLIC RATE (HR) OF PILOTS DURING AGRICULTURAL FLIGHTS ON VARIOUS TYPES OF AIRPLANES AND HELICOPTERS

type	rest before takeoff		immediately before takeoff		take off		final approach flight		flight over obstruction		180° turns		landing		after landing	
	HR	[%]	HR	[%]	HR	[%]	HR	[%]	HR	[%]	HR	[%]	HR	[%]	HR	[%]
PZL-101	73	100	83	114	96	131	100	137	120	164	96	131	125	171	108	148
An-2	75	100	98	131	110	147	96	128	116	155	108	144	104	140	98	131
SM-1	66	100	83	126	81	123	87	132	—	—	92	136	78	118	—	—
Mi-2	72	100	84	117	99	137	106	147	—	—	106	147	101	140	—	—
Arithmetic mean	71		87		96		97		117		100		102		103	

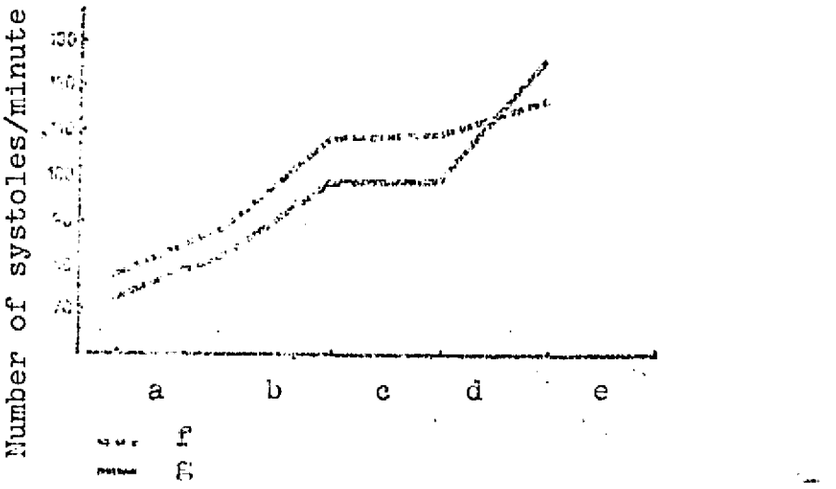

Fig. 2. Comparison of systolic rate during agricultural flight on PZL-101 airplane in terrain at base of mountain and in lowland terrain

Key: a) Rest b) Before takeoff c) Takeoff d) 180° turns e) Landing f) Terrain at base of mountain g) Lowland terrain

TABLE 2. COMPARISON OF SYSTOLIC RATE (HR) DURING AGRICULTURAL FLIGHT ON PZL-101 AIRPLANE IN TERRAIN AT BASE OF MOUNTAIN AND IN LOWLAND TERRAIN

a	b									
	c		d		e		f		g	
	HR	j [%]	HR	j [%]	HR	j [%]	HR	j [%]	HR	j [%]
h	73	100	83	114	99	131	95	131	125	171
i	78	100	86	110	108	138	106	136	115	147

Key: a) Terrain b) Flight phases c) Rest d) Before takeoff e) Takeoff f) 180° turns g) Landing h) Lowland i) Base of mountain j) Changes (%)

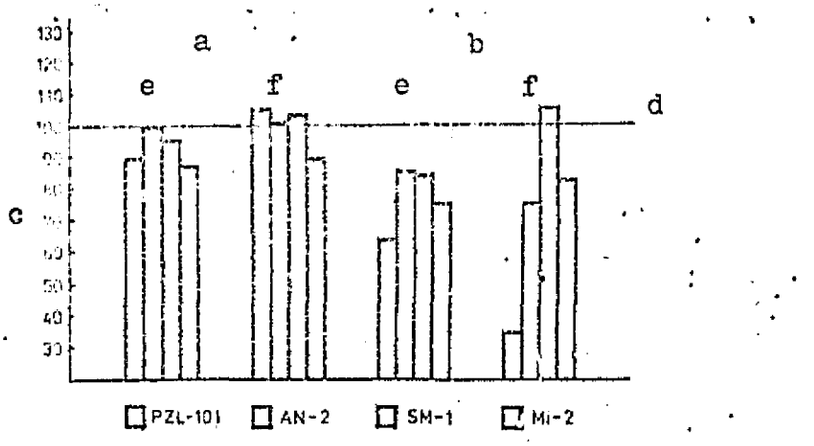

Fig. 3. Changes in strength and endurance of flexor muscles in fingers after agricultural flights on various types of airplanes and helicopters

Key: a) Strength b) Endurance c) Rest
d) Percent changes e) Left f) Right

TABLE 3. STRENGTH OF FLEXOR MUSCLES IN FINGERS AFTER AGRICULTURAL FLIGHTS ON VARIOUS TYPES OF AIRPLANES AND HELICOPTERS

a	b					
	c			d		
	e (kg)	f [kG]	g [%]	e [kG]	f [kG]	g [%]
PZL-101	52	47	90	50	54	108
An-2	55	55	100	55	55	100
SM-1	44	42	95	46	47	102
MI-2	60	52	87	62	56	90

Key: a) Type
b) Strength of flexor muscles in fingers of
c) Left hand
d) Right hand
e) Before flight (kg)
f) After flight (kg)
g) Changes (%)

TABLE 4
ENDURANCE OF FLEXOR MUSCLES IN FINGERS AFTER AGRICULTURAL FLIGHTS ON VARIOUS TYPES OF AIRPLANES AND HELICOPTERS

a	b					
	c			d		
	e [s]	f [s]	g [%]	e [s]	f [s]	g [%]
PZL-101	41	25	61	57	21	37
An-2	29	25	86	31	23	74
SM-1	40	34	85	34	40	118
Mi-2	98	72	74	139	117	84

Key: a) Type b) Endurance of flexor muscles in fingers of hand c) Left d) Right e) Before flight (sec) f) After flight (sec) g) Changes (%)

values (sic) during rest on the PZL-101 airplane and to 70% of the values during rest (sic) after flights on the An-2 airplane (Table 4 and Fig. 3). Marked prolongation of the time used up to carry out the test due to greater trembling of the hand was also detected in tremorometric tests after a series of flights.

Comparison of Stress in Pilot During Agricultural Flights Over Lowland Terrain and Terrain at Base of a Mountain

The work of the pilot above terrain at the base of a mountain is characterized by a higher degree of control difficulty. The relief of the terrain makes it difficult to select suitable landing grounds which, in addition, in most cases, have a shorter than optimal takeoff strip. In piedmont conditions, the therman winds also have a specific character resulting in sideslipping on slopes and in eddies, which in turn requires in addition the ability to predict thermic conditions depending on the relief of the terrain. Good visibility (which is limited in the case of the PZL-101 airplane) is indispensable for this purpose. These exceptionally difficult conditions have compounded considerably

the difficulty of agricultural flights above lowland terrain. This applies in particular to such flight phases as takeoff and the performance of 180° turns (Table 2). The persisting high systolic rate (about 115 systoles per minute) while landing during the performance of 5-10 consecutive flights also deserves attention. This phenomenon can be explained by maximum mobilization of the body's reserves under these conditions. On the other hand, during the /15
performance of an activity characterized by physical stress, i.e., while making a 180° turn and during the spraying of chemicals, the observed systolic rate increased to 137% of the value during rest, with an increase in body stress in each successive flight. At the same time the emotional stress associated with a takeoff decreased. This fact is indicated by the systolic rate, which was 117% of its value during rest before the fifth flight, 108% of its value during rest before the fifteenth flight and 105% of this value before the twenth-fifth flight. This may indicate a certain degree of adaption to definite takeoff conditions.

Comparison of Stress on Pilot During Agricultural Flights in Airplane and Helicopter

Compared to an airplane, a helicopter appears to have several important advantages during the performance of agricultural tasks. These include, among others, easy takeoff and landing and less stringent requirements in regard to meteorological conditions. In view of this we should anticipate a lesser degree of stress both before takeoff and during the flight. The comparison of the data was also useful because of complete lack of information on the subject of stress on a helicopter pilot during agricultural flights.

Depending on meteorological conditions, a helicopter pilot's working day is about 5 hours. On individual dlight lasting up to 10 minutes, it is limited by the capacity of the tanks

containing the chemicals. The pilot's cabin provides good visibility and the strength required to service the control devices is negligible (especially in an Mi-2 helicopter).

The highest systolic rates during flight in a SM-1 helicopter were recorded while performing such activities as a 180° turn and flying above a field (Table 1). On the other hand, the systolic rate was lower during takeoff and landing. The values of indicators of the strength of flexor muscles in fingers of the hand decreased by 5% after the completion of a series of flights (Table 3), and the values of endurance indicators decreased by 15% (Table 4). The values of the threshold for sending vibrations increased in the entire range of the spectrum investigated by about 5 dB (or slightly more), and by about 10 dB in the range of 400, 500, and 640 HZ frequencies. This decrease in sensitivity is related to the transfer of mechanical vibrations from the helicopter control devices to the pilot's hand.

During flights on an Mi-2 helicopter, the highest cyctolic rates were recorded in the first series of flights while performing 180° turns and during landing (up to 140 systoles per minute). In subsequent flights the systolic rhythm slowed down to about 115 systoles per minute.

Values of the muscular strength indicator, measured after the flights were completed decreased to 87-90% of their values during rest, whereas values of the indicator of the endurance of muscles in the hand decreased to 74-84% of their value during rest. The threshold for sensing vibrations increased slightly in the range of low frequencies and decreased (from 3 to 17 dB) in the range of higher frequencies. It appears that this shift in the vibration sensing threshold may be related to functional hyperemia of the hand; however, a complete interpretation requires measurements of the vibration spectrum of the control lever.

Conclusions

The results of the studies presented by us must be interpreted with great caution due to the following facts:

-- small number of pilots available for studies,
-- variable observation conditions (time of year, time of individual flights or entire series of flights sometimes simulating the activities performed),
-- different flight experience before the studies began under natural conditions.

An interesting phenomenon, based on our observations should be emphasized, namely, the lower psychological efficiency of pilots before the series of spring flights compared with the fall series. This fact is evidenced by the higher systolic rate during rest, the longer reaction time and the higher threshold for sensing vibrations. Possibly these differences are the result of a seasonal efficiency rhythm.

The results obtained indicate a relatively high degree of stress on the pilot during the performance of agricultural tasks, accompanying preparations for the flight and individual flight phases. One fact which should be emphasized is that the group studied consisted of pilots with the highest qualifications and extensive professional experience. The analysis of fatigue occurring in agricultural flights seems to suggest the conclusion that the maximum safe flight period throughout which a pilot can be subjected to stress is 3 hours. A marked deterioration in the pilot's psychophysical efficiency is observed after this period. The stress on the pilot during helicopter flights appears to be lower than the stresses occurring during the control of an airplane. On the basis of the physiological results obtained, we can assume that the following factors contribute to stress on the pilot: physical effort involved in operating /16

control and regulating devices, inconvenient position during flight, considerable emotional stress and adverse conditions in working environment (adverse microclimate, noise, presence of toxic substances and transfer of vibrations to pilot's tissues).

In view of these observations, optimization of the pilot's working conditions must proceed along the following lines:

- -- reduction of tightness of lever, rudder bar, gas throttle lever, mechanism for release of chemicals and trim tab control in PZL-101 airplane,
- -- take into account specific structure of pilot's activities during agricultural services in the design of working space (placement of gas and propeller pitch regulating levers closer to each other and placement of lever for release of chemicals on control stick),
- -- reduction of noise and vibration level
- -- protection from exposure to effect of toxic substances (cargo on side, hermetically sealed cargo and cabin),
- -- improved body position and ensuring precision of activities performed.

The analysis of stress on the pilot presented above should be regarded as a preliminary study before a complete evaluation of working conditions is accomplished.